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configuration of flow production systems*

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# INVESTIGATION OF ECONOMIC ALTERNATIVES FOR THE CONFIGURATION OF FLOW PRODUCTION SYSTEMS

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## ABSTRACT

In order to achieve a given output of a product in the planned period, the structure of the flow production system must be considered and selected. The structure alternatives differ from each other with the numbers of identical parallel flow lines, station numbers in each line and the cycle times.

In the department for industrial engineering at Ilmenau University of Technology, a strategy for optimization of identical flow lines was developed so that the parallel buffers were combined with each other. The previous investigations of this strategy defined many logistical advantages. For this reason it is useful to organize and carry out further investigations which may lead to the use of this strategy in the industry.

Based on an example, alternatives for planning and combination of identical flow lines are studied and presented. Furthermore, this paper offers two models for the realization of the tested flow system.

**Index Terms** – Identical flow lines, precedence graph, work station, buffer capacity, MTTR, throughput, delay times, simulation

## 1. INTRODUCTION

The required processing time for producing a product in a flow line consists of individual work items. One assumes that this can be not divided [1]. The goal is often the most efficient allocation of work elements at work stations in flow production lines. Here two challenges are to be considered. First, the amount of work must be distributed as equal as possible among the stations in order to reduce waiting times and / or blocking times. Second, the processing times of stations must be determined and balanced, so that the desired amount of product can be achieved.

In this paper, the example of B2 in [2] –for the configuration of flow production lines- is selected, analyzed and optimized respectively. Fig. 1 shows a precedence graph<sup>1</sup> for example B2, in which the circles represent the individual work elements and the arrows indicate the precedence relationships between them. The processing times of work elements are shown above the circles. In principle, the distribution of the work amount at the processing stations in a production line must be made as equal as possible with the principle of SALBP. For the balancing of station workloads in the linear flow system the technical literature offers a lot of researches, such as [3], [4].

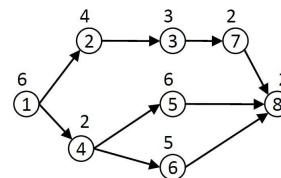


Fig. 1: A precedence graph for the example to be examined

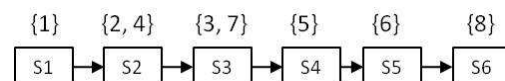


Fig. 2: Distribution of the work amount at 6 stations

In order to achieve a throughput of one product per 6 units of time, the work items are distributed as in Fig. 2. If the need product quantity is 3 times higher, three identical lines must be provided. Is this the only solution? The increased production rate in a flow line requires a reduction of the maximum processing time of the station by increasing the number of stations. But this is not possible in this example. In [2], a formula was mentioned (1) for the configuration of identical

<sup>1</sup> A precedence graph represents the necessary tasks and the relationships between them.

production systems, and then three alternatives were presented in fig.3.

$$\text{Should - be output quality} = \frac{\text{working time}}{\text{cycle time}} \times \text{the number of identical parallel flow lines} \quad (1)$$

each other by buffers. To construct the new model, the side-by-side stations each of the equal lines (symmetrical arrangement) are connected by a common exit buffer (see Fig. 5).

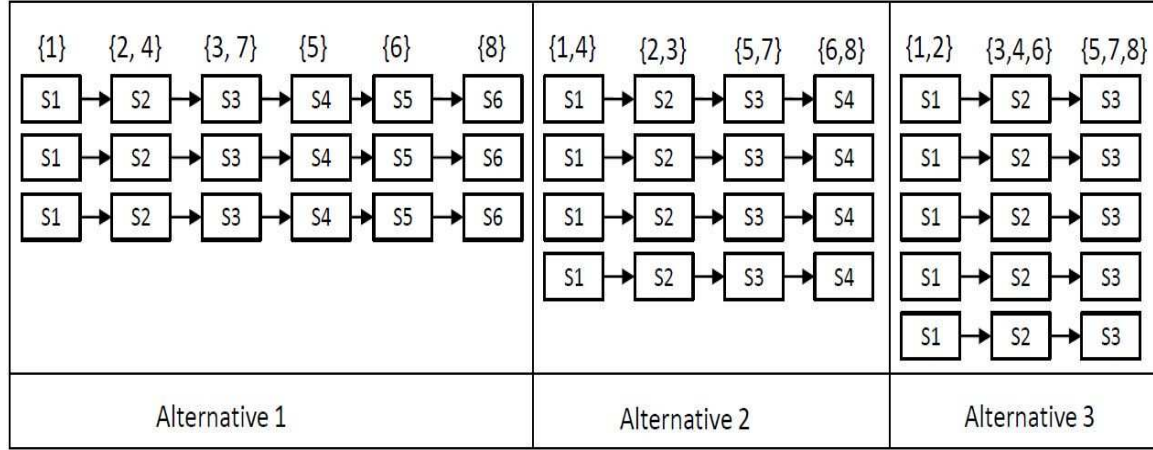


Fig. 3: An example of structure alternatives for a flow production system

The numbers between brackets are the number of work items. In each structure alternative, the number of identical flow lines, station number and cycle time change.

The mentioned study has focused on the method of distribution of work amount in stiff linked flow lines. This linkage type is not generally classified as economical because of the huge increasing the blocking and waiting time at the last station of a flow line. In consideration of the three structures in fig. 3 they lead to the following:

- Small station cycle times increase the number of stations and thus the linkage losses.
- The larger the number of elements at a work station, the more complicated the work tasks that are carried out and lower their technical availability.

Taking into account that with complex systems, the overall availability does not exceed the value 98% [5] and that the processing times can vary, for example, in manual labor, thus buffers between the stations are provided. The new structure of the alternative 3 is shown in Fig. 4.

## 2. COMBINED IDENTICAL FLOW LINES

Buffers in a manufacturing line provide compensation for differing machining times at successive stations. Buffers may be arranged between two stations each, (Fig. 4) so that the component numbers of the manufacturing lines will double and capital outlay cost will increase. Considering several flow lines producing equal products there is a demand for optimization of such lines and for reduction of costs. For this purpose, Flow lines are connected to

According to [6], [7] the combined structure has the following advantages:

- Significant reduction of buffer capacity. In this case, the reduction could be up to 80%. This advantage is further presented in this paper.
- Reduce the required system surfaces: The new structure provides that the areas of buffers which are no longer necessary, hence the areas for these buffers previously arranged in-between the manufacturing line are gained. The larger the difference between the machining times, the larger the buffer capacity to be provided.
- Reduction of failure effects consequences: In the new configuration, parallel stations each are supplied with work pieces by one input buffer and the finished work pieces are supplied to an exit buffer so that there are no direct connections between the stations. If failure occurs at a station, so its effect on the flow line will be relatively small as the following stations will be fed by a common input buffer and simultaneously the upstream stations will be disposed of work pieces in the relevant common exit buffer.
- Increasing the overall availability of the flow system: Depending on the occupancy status, empty status or a jammed status of the next parallel stations the work pieces are forwarded from the buffer to the free stations. The stations can be described as redundant. The increase in the overall availability of combined structure is higher, the smaller the availability of the individual

stations and the larger the combined buffer capacity -in general the bigger the time losses in conventional structure-.

- Increasing of total throughput: As each entrance buffer in the combined flow line is fed by many stations, If failures occur, the waiting time at the following stations is reduced which results in an increase of throughput. However, in specific cases, significant increase in throughput can be obtained by the addition of additional stations to the parallel stations for balancing the cycle times.

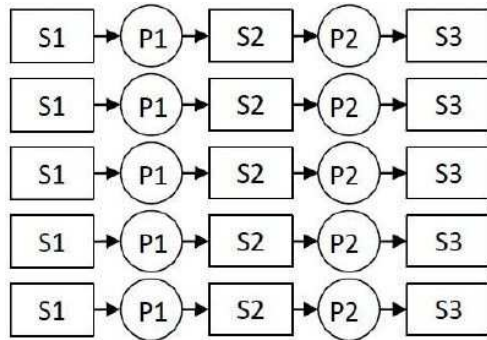


Fig. 4: The elastic linked structure of alternative 3

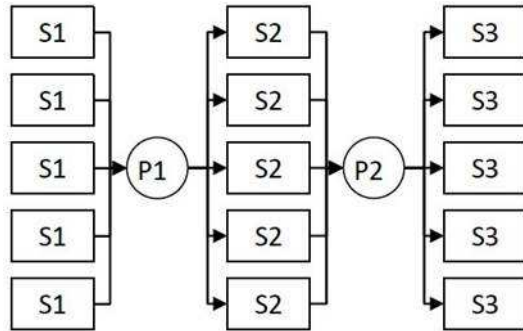


Fig. 5: The combined linked structure of alternative 3

### 3. ALTERNATIVES FOR THE REALIZATION OF THE COMBINED STRUCTURE

A challenge for the practical use of this strategy is to realize a connection between the parallel stations without losing the benefits listed above. For example, the transport times must be equal or almost lower than in conventional structures. Furthermore, a question arises: how can a maintenance worker perform his duties at the stations or even remove a failure at them without the obstacles of combined buffers?

Depending on the buffer type in the conventional structure, the corresponding combined buffers are organized. Assuming that the buffers are shown in Figure 3 as a roller conveyor, the combined buffer can be designed as roller conveyor too, so the work piece can move in one or two directions (see Fig. 6

Alternative 1 und 2). In the last section, it was noted that the capacity of combined buffers can be significantly reduced without reducing the throughput. In this case, the combined buffers can be designed as in alternative 2. Looking at the fig. 6, we see that in the combined structures, the material flow is no longer linear, the maintenance ways are shorter and the required system surfaces are significantly less.

### 4. INVESTIGATION OF TRANSPORT TIME (DELAY TIME)

As mentioned before, to ensure the benefits of using this strategy, the transport times or pick-up times in combined structure must be equal or lower than in conventional structures. This challenge is often noticeable when the buffer capacity is very small, the number of parallel work stations and the distances between them are large.

We cannot use the processing time of work item in the last example of [2] because they were not dictated by concrete "time units". To select the simulation data for the buffers and work stations in the flow lines practically, typical data -which most suitable for our model- must be searched in technical books. According to [8], the cycle times of work stations exist between 1 and 30 seconds. The accumulation is between 3 and 10 seconds. The mean availability values of stations locate at 94.8% [8]. By Assembly processes, the failure durations are mostly less than 3 minutes [9]. Depending on the used conveyor means and manufacturers, the driven roller conveyors can achieve 0.3 to 0.5 m/s [10].

Based on the conducted research the following simulation data are assumed:

- Because of many work items can be performed at a station in the Alternative 3, the typical processing time of stations can be assumed 15 sec.
- The delay times in buffers vary between 0 and 20 sec. The value of 0 sec was examined in order to compare this -the ideal case- with other values, so the effects of the delay time in buffers can be seen clearly.
- Two availability values of work stations 90% as well as 95% and mean duration of failures MTTR 2 as well as 3 minutes will be investigated.
- Study duration 2 days (48 hours)

In the first study, we assume that the station availability is 95% and MTTR equals 2 minutes. So as to reduce the failures effects, the buffer capacity must be large enough designed.

Required buffer capacity =  $2 \cdot 60 / 15 = 8$  buffer spaces

According to [6], the buffer capacities in the combined structure and in the conventional structure may be equal.

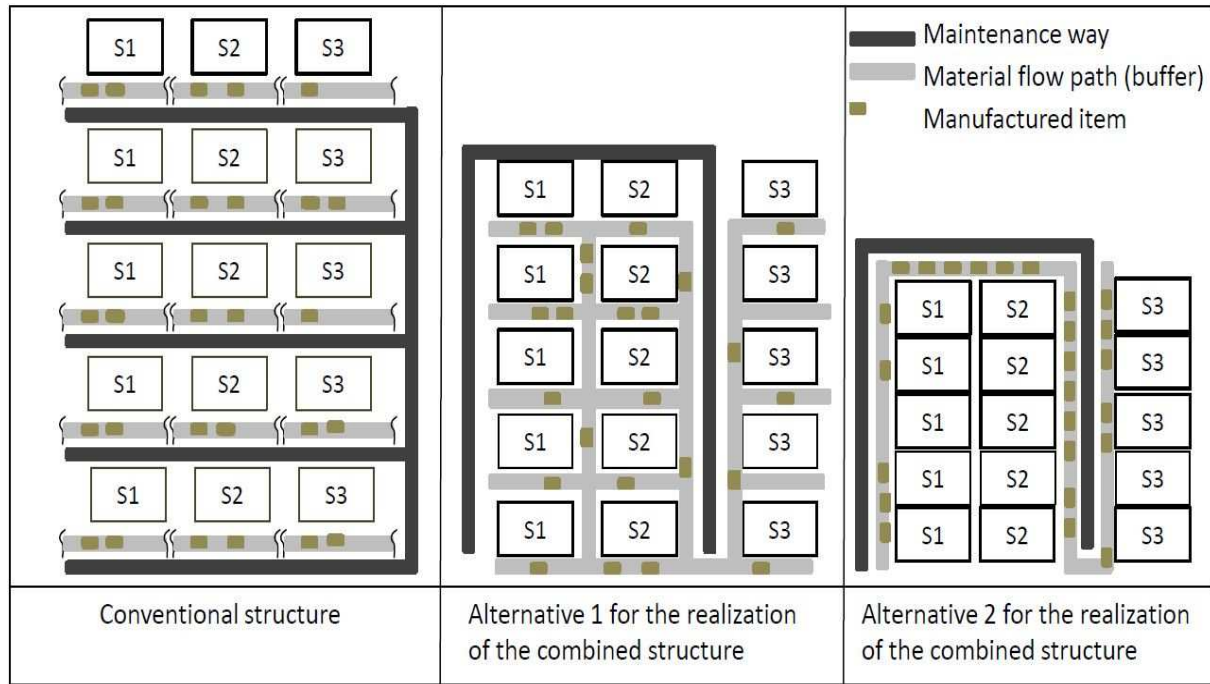


Fig. 6: Two alternatives for the realization of the combined structure

This assumption is also considered in these simulation experiments. The output of simulation is the throughput (pieces / hour).

Looking at the graph derived from the simulation (see Fig. 7) it is striking that the throughput in the conventional and combined structure with time delay in buffers of 15 sec is almost the same. That means the realization of the combination is mostly of importance if the delay time is less than 15 sec. This is explained by the fact that the emptying and filling of the combined buffers take place much more common than in buffers in conventional structure. The delay time have only influence on the throughput, if the buffer is empty and new product moves through it. In this case, the successor stations wait for him until it passes through the buffer.

In the second study, the station availability of 90% is examined. The simulation results show that the combination of flow lines is advantageous up to the value of delay time 20 sec. (see Fig. 8). Noticeable is that the difference between throughputs of combined as well as conventional structure and stiff structure increase. This means the buffers have avoided more time losses in the two structures in comparison with stiff structure (blocking and waiting times).

Analogous to the previous studies, two experiments with the variation of station availabilities and MTTR and thus buffer capacities are carried out (see Fig. 9 and 10).

It is known that the reducing of availability values and the increasing of MTTR lead to increased time losses. In contrast, the increase of buffer capacities result a better reduction of time wastes. Although the deterioration of the values of system parameters in these two experiments, the fig. 9 and 10 show nearly equal values of throughputs in a combined structure. The result is that the new structure has the best ability to reduce the negative effects (time losses).

## 5. CONCLUSION

The combination of identical flow lines complicates the resulting overall system while increasing its overall availability, its work load and primarily the total throughput. Furthermore, this combination entails a significant reduction of required buffer size in excess of 50% depending on the number of parallel flow lines. The current and previous studies on the combined flow lines in the department for industrial engineering have demonstrated that this strategy is of great importance and it can lead to economic solutions by the configuration of flow lines. For the realization of the combined structure is important to define, what buffer type is capable for the combined flow lines, which don't lead to increase the delay time and the control effort? This paper presents an example of the configuration and combination of identical flow lines. Furthermore, it offers economical alternatives for the realization of the optimized model.

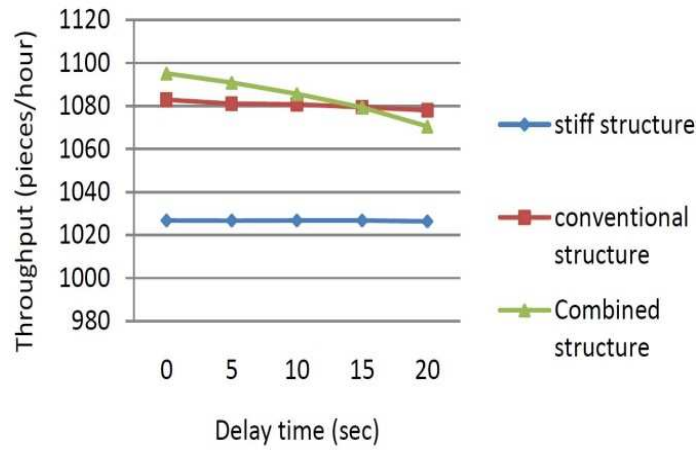


Fig. 7: Simulation results with the variation of station availability ( $A=95\%$ ),  $MTTR=2$  min and buffer capacities ( $B=8$  buffer spaces)

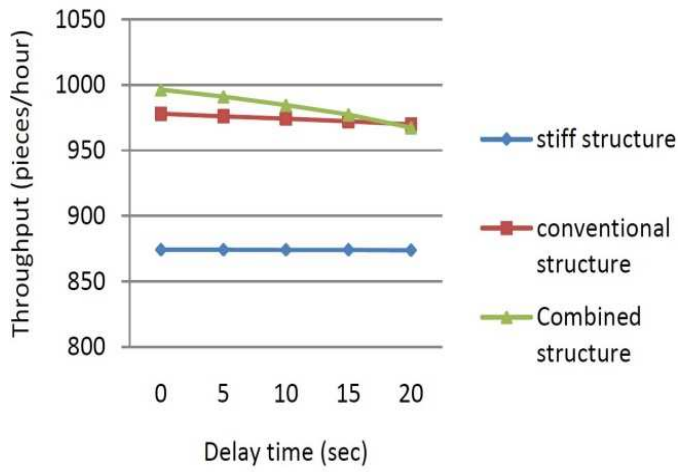


Fig. 8: Simulation results with  $A=90\%$ ,  $MTTR=2$  min,  $B=8$  buffer spaces

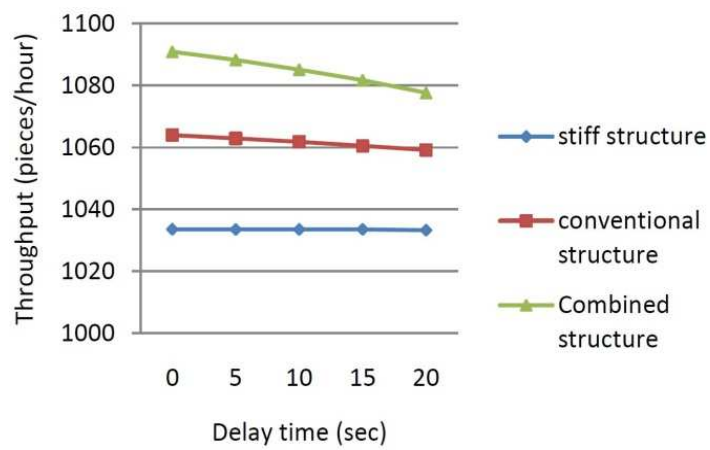


Fig. 9: Simulation results with  $A=95\%$ ,  $MTTR=3$  min,  $B=12$  buffer spaces



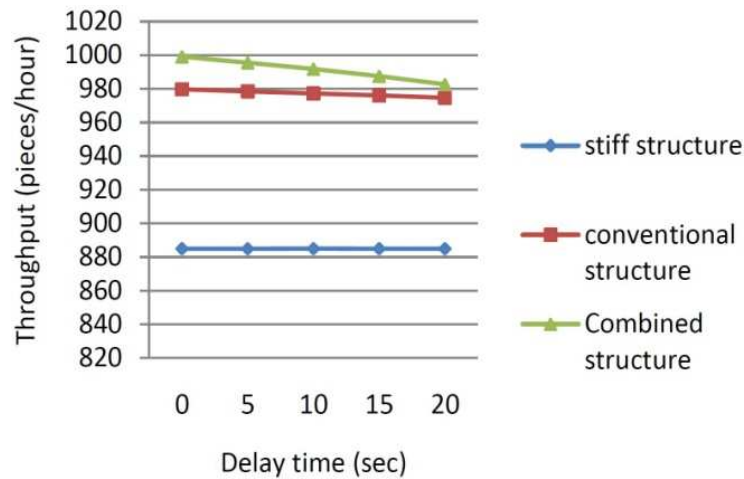


Fig. 10: Simulation results with  $A = 90\%$ ,  $MTTR = 3 \text{ min}$ ,  $B = 12 \text{ buffer spaces}$

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